



CONTRACT-BASED AIR TRANSPORTATION SYSTEM (CATS)

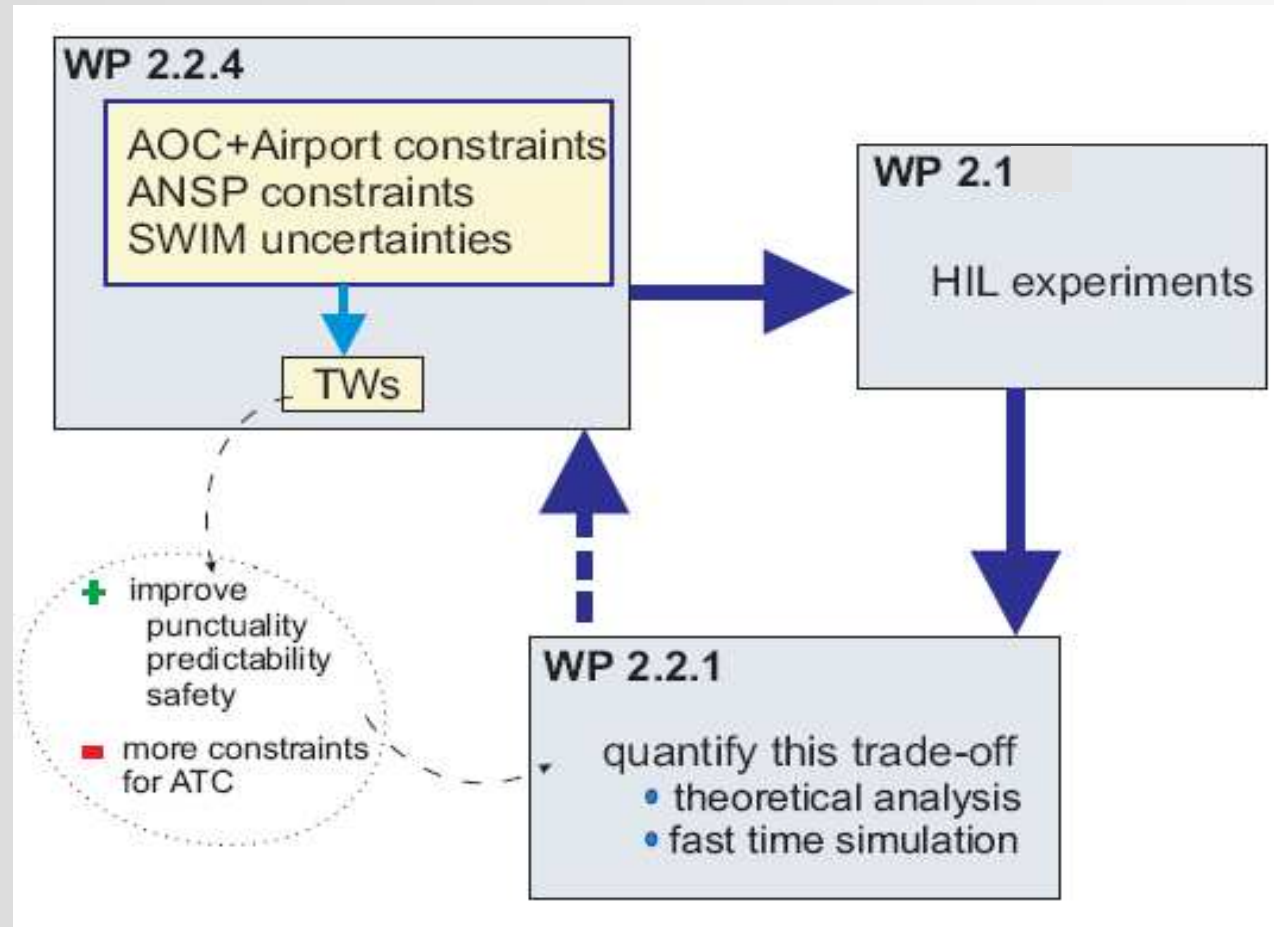
Risk and Safety Assessment

Kostas Margellos and John Lygeros
ETH Zurich

Objectives

- Complement the HIL studies
- Provide insight regarding the TW size
 - Feedback to TW modeling
 - Statistical analysis based on Monte Carlo methods
- Safety analysis
 - Determine the maneuvering freedom afforded by each TW
 - Conflict detection and resolution under TW constraints
 - Theoretical analysis based on reachability and game theory
- Enabling technology for fast time simulation
 - Human controller not available
 - Develop algorithms for
 - meeting TW requirements
 - Time of Arrival controller for TW tracking in fast time simulation

Role in the project



Outline



- Statistical analysis based on Monte Carlo
 - Comment on the TW size

- Safety analysis
 - Conflict detection and resolution under TW constraints

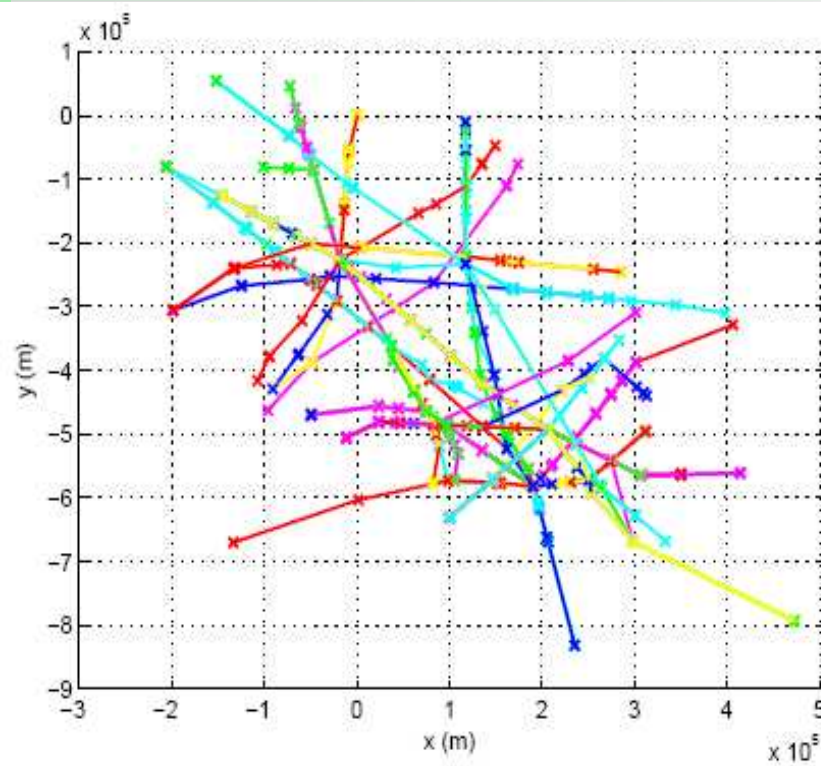
- Time of arrival control
 - TW tracking in fast time simulation

Fast time simulation set up

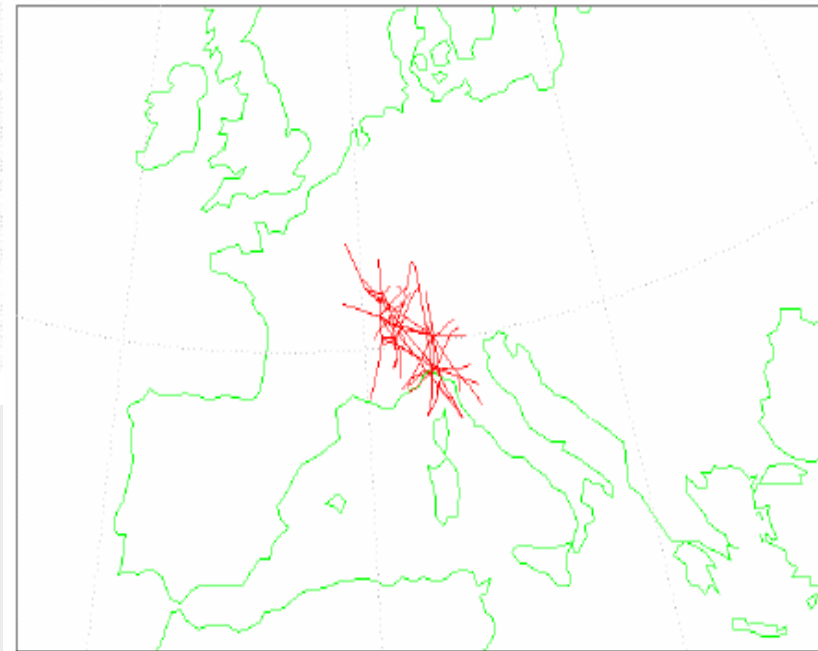


- HIL 2 set up in fast time simulator
 - Point mass aircraft model
 - Reasonable from the ATC point of view
 - FMS for flight plan tracking, cruise, climb, descent, etc.
 - BADA parameters
 - Realistic wind uncertainty
- Implementation issues
 - Java simulator
 - Fast, object oriented → better for dynamic setup
- Uncertainty sources
 - Wind, nominal mass, airspeed, entry point uncertainty
 - Flexible to add more e.g. air density, temperature ...

Fast time simulation set up



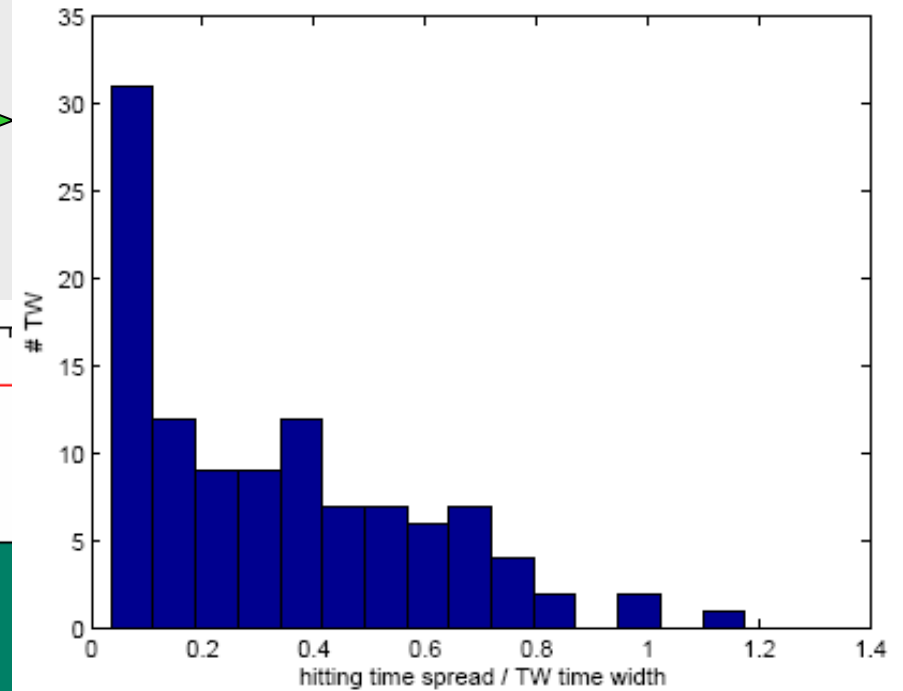
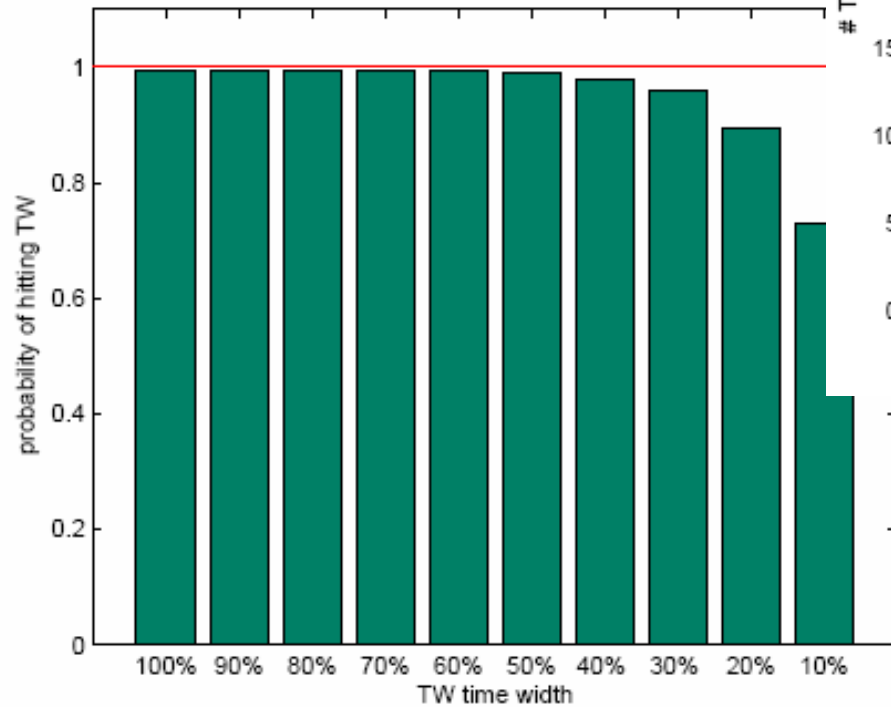
- 50 flights from HIL 2
- Monte Carlo
 - 1000 simulations



Simulation results

Case 1: Wind uncertainty

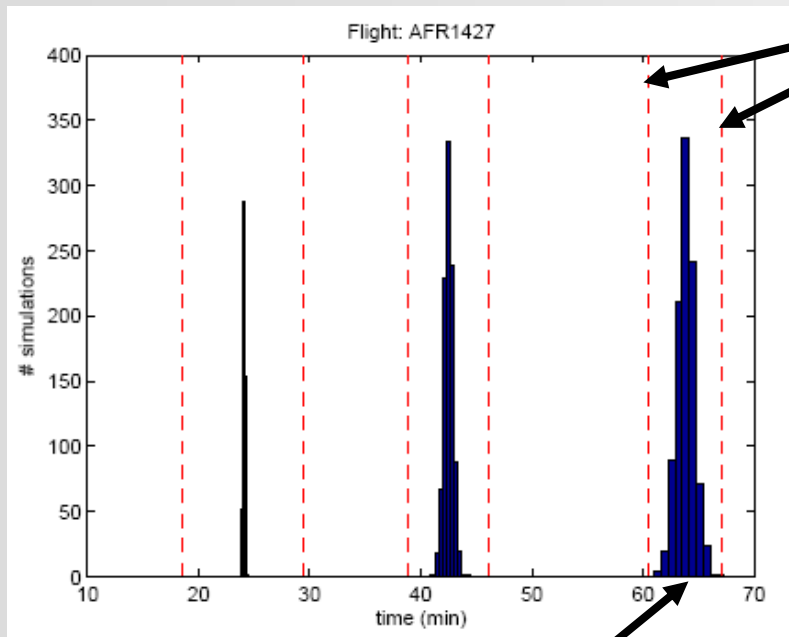
TW's size indicator



Probability of TW hitting

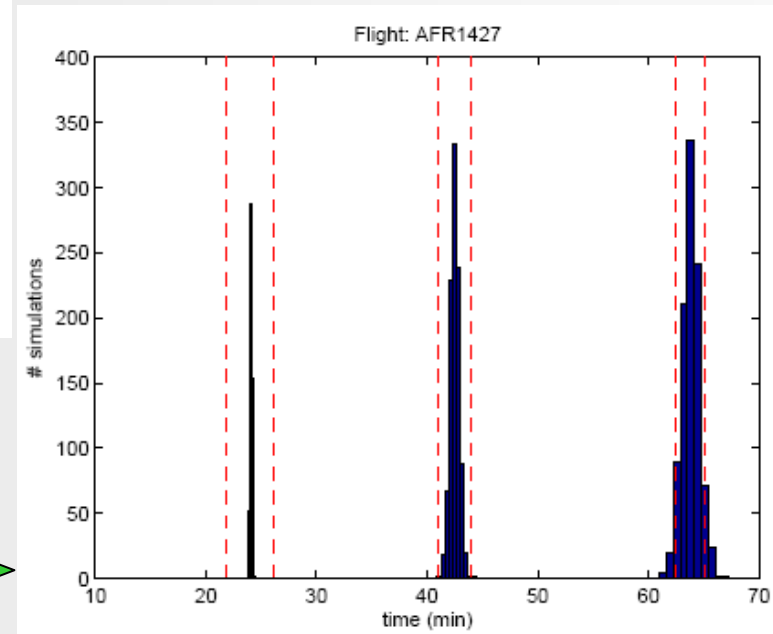
Simulation results

Case1: Wind uncertainty



TW time width

100% of TWs size



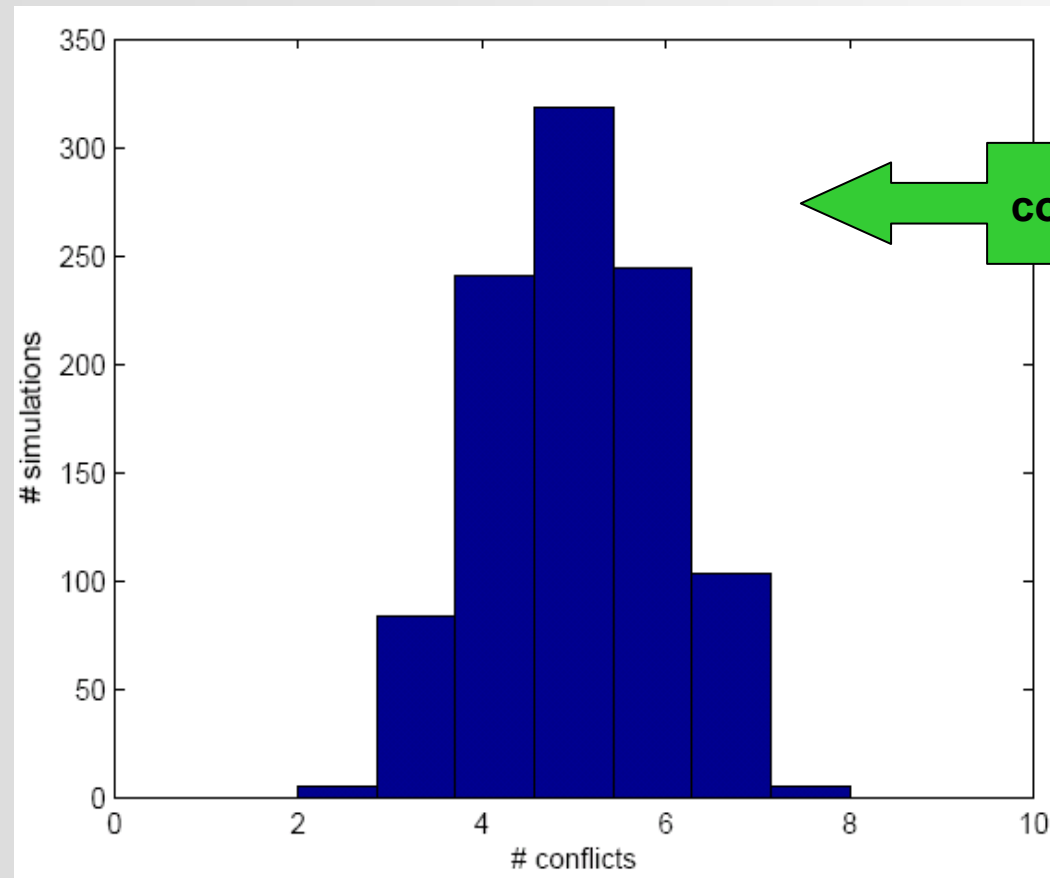
hitting time spread

40% of TWs size

Simulation results

Case 1: Wind uncertainty

- Conflict detection for 50 flights and 1000 simulations

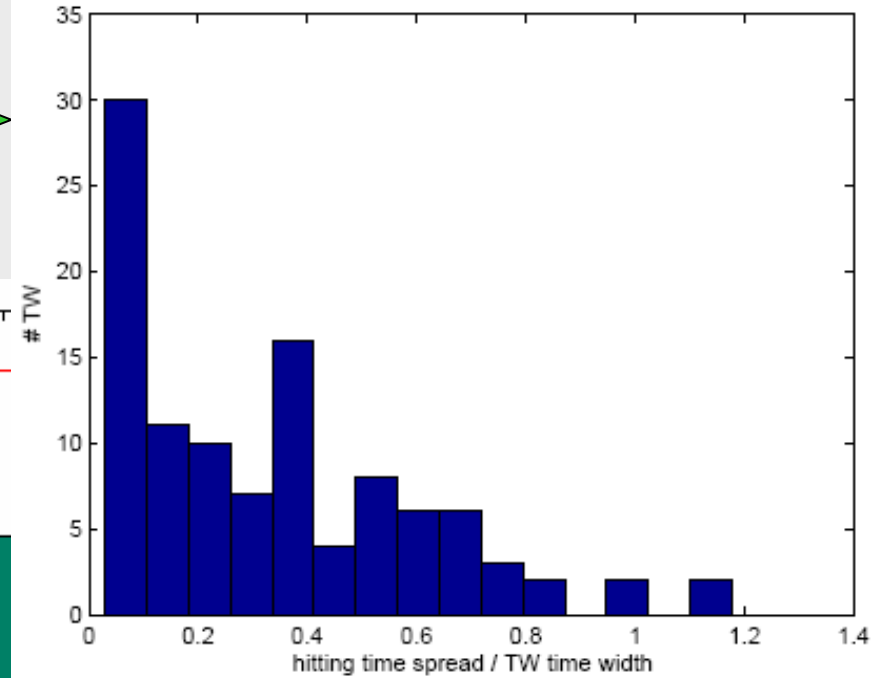
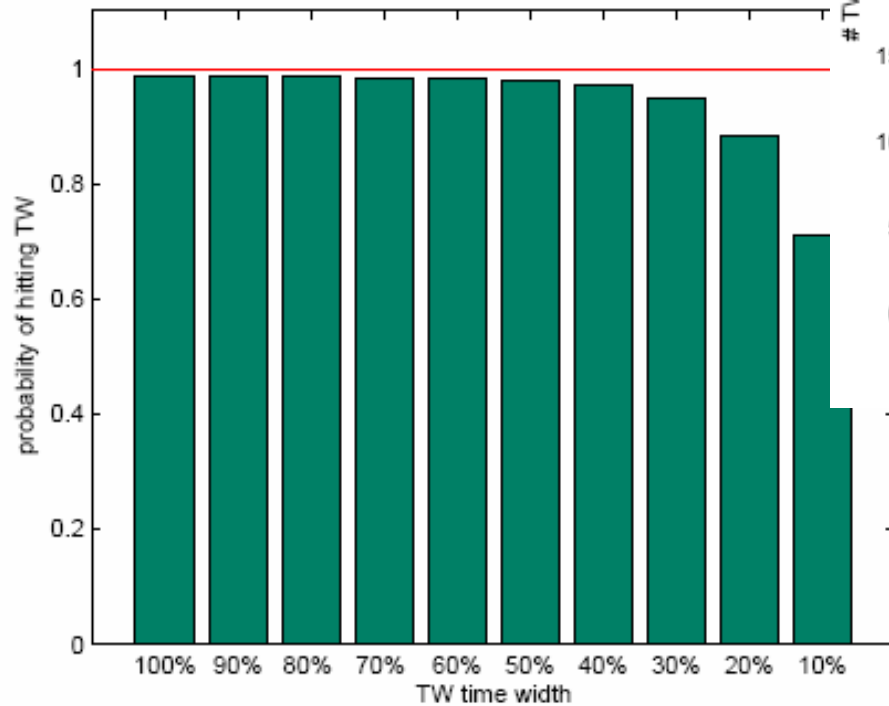


← conflicts encountered

Simulation results

Case 2: Wind + mass uncertainty

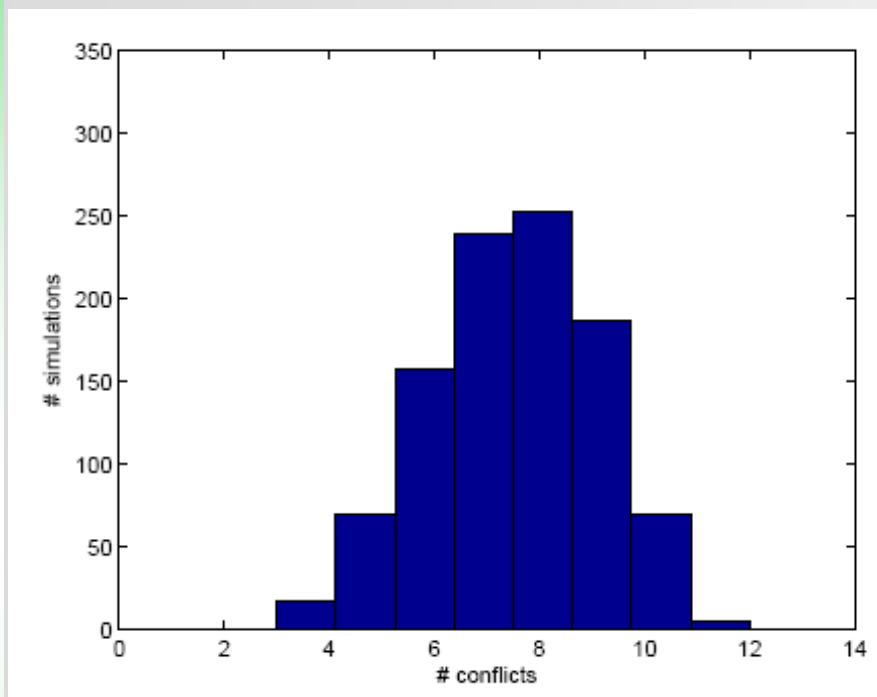
TW's size indicator



Probability of TW hitting

Simulation results

Case 2: Wind + mass uncertainty



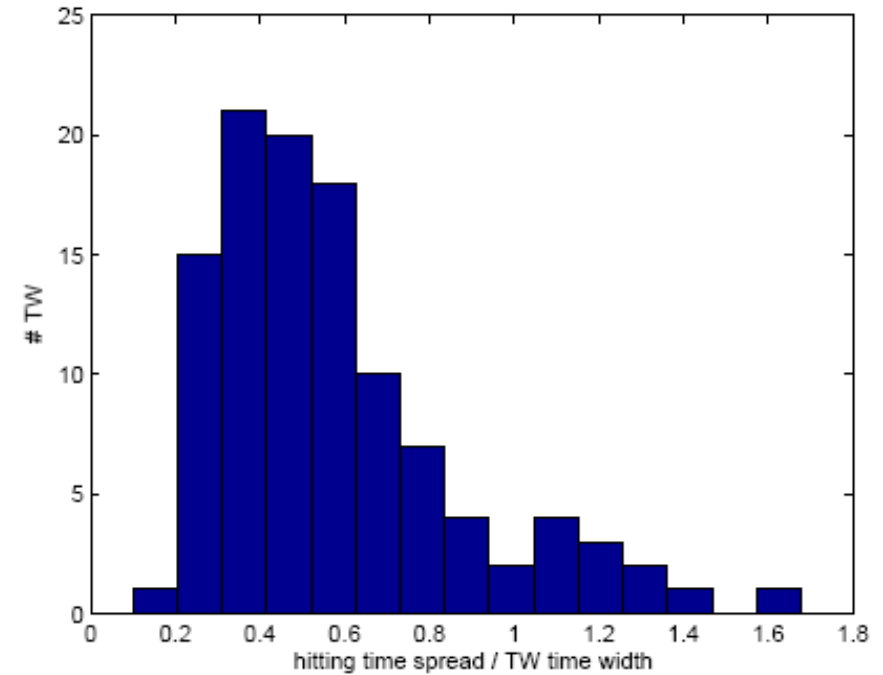
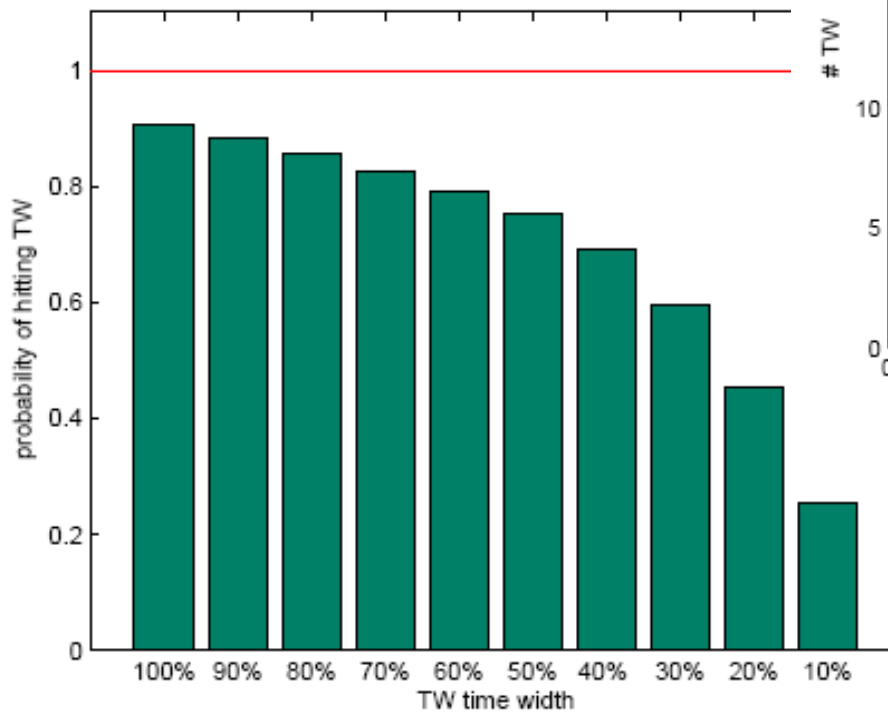
← conflicts encountered

- Mass uncertainty has a minor impact
 - Conflict and TW hitting probability almost identical with case 1

Simulation results

Case 3: Wind + mass + entry point uncertainty

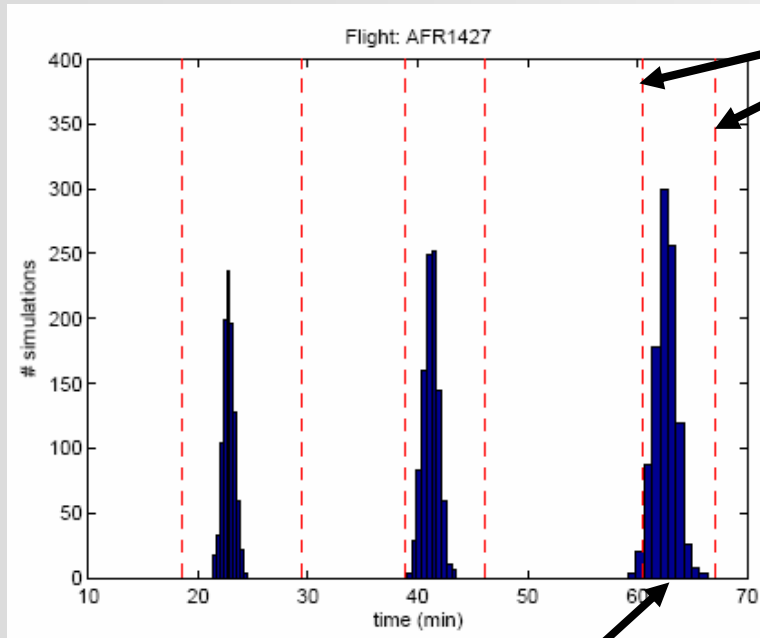
TW's size indicator



Probability of TW hitting

Simulation results

Case 3: Wind + mass + entry point uncertainty



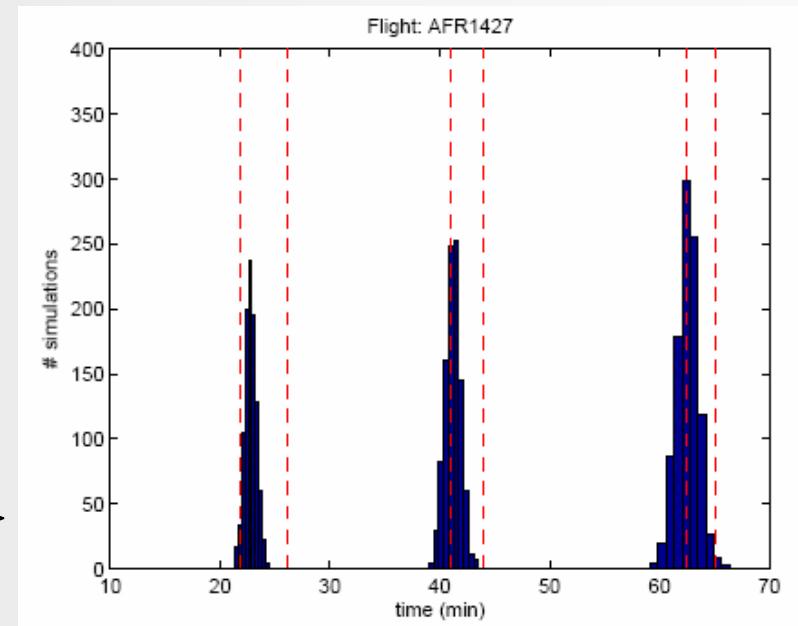
TW time width

100% of TWs size



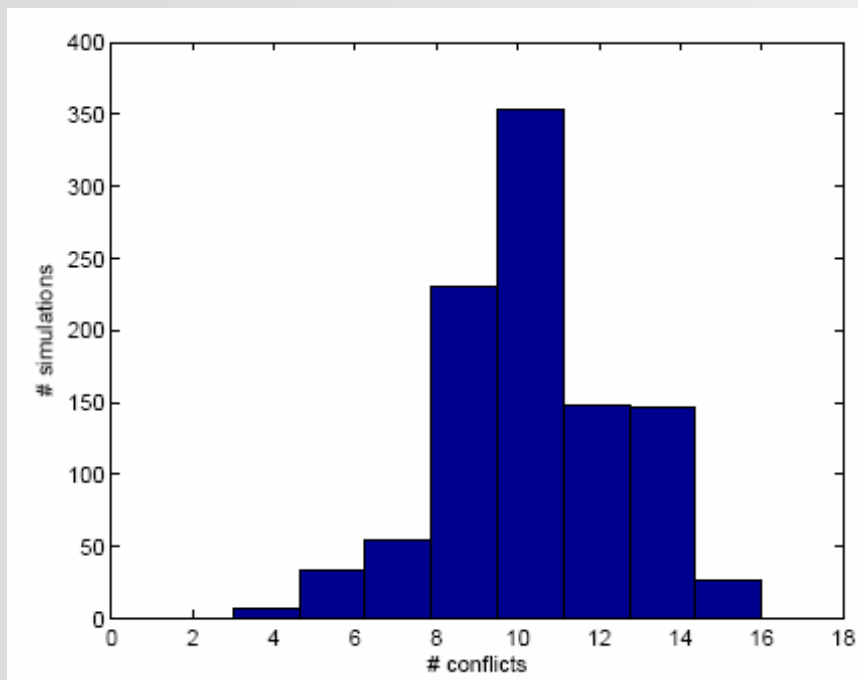
hitting time spread

40% of TWs size



Simulation results

Case 3: Wind + mass + entry point uncertainty



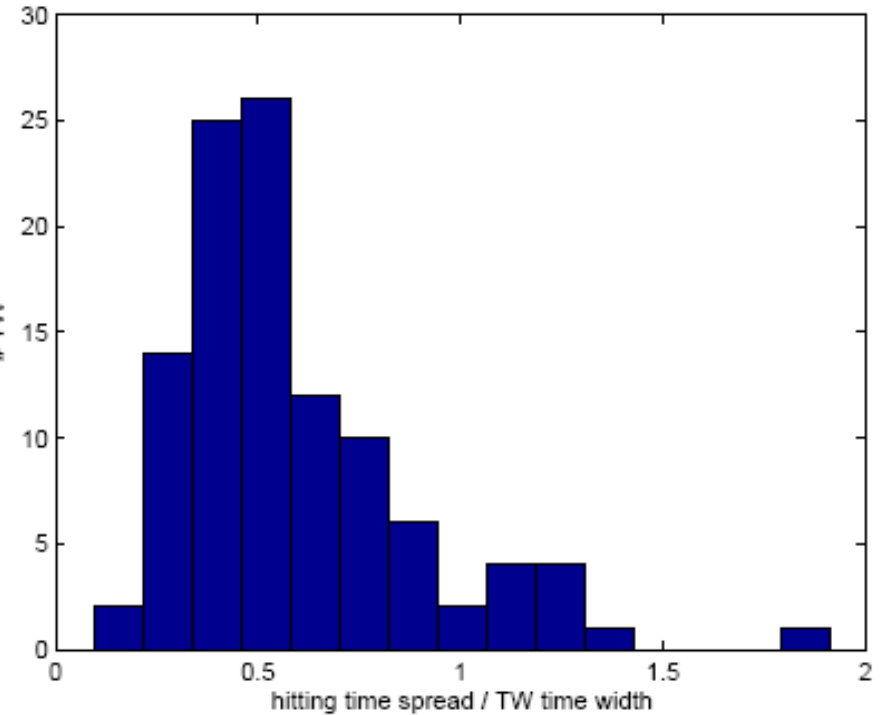
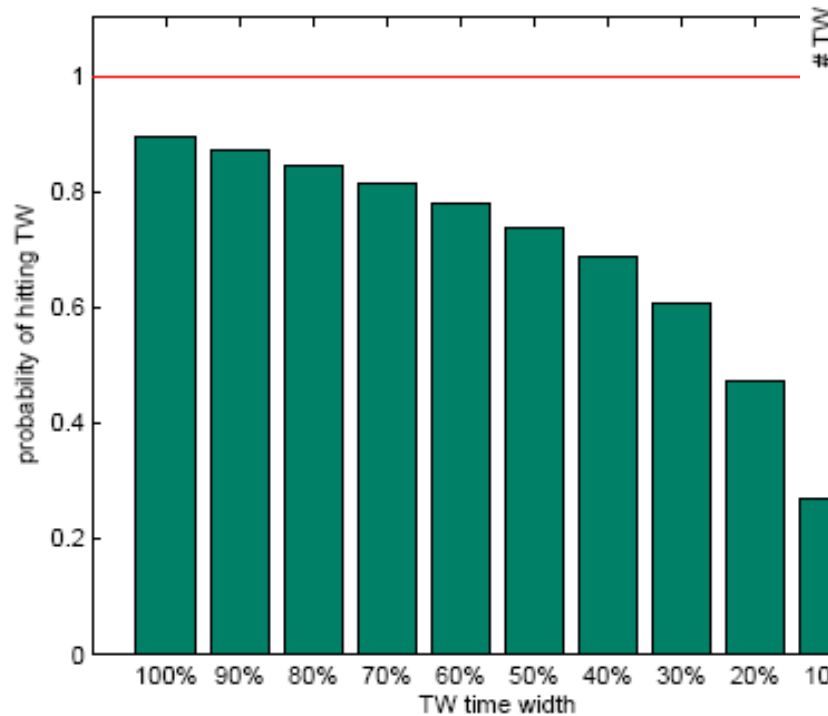
← conflicts encountered

- Uncertainty in the entry time has a major impact
 - Increased number of conflicts
 - Reduced TW hitting probability (compared to cases 1 and 2)

Simulation results

Case 4: Wind + mass + entry point + airspeed uncertainty

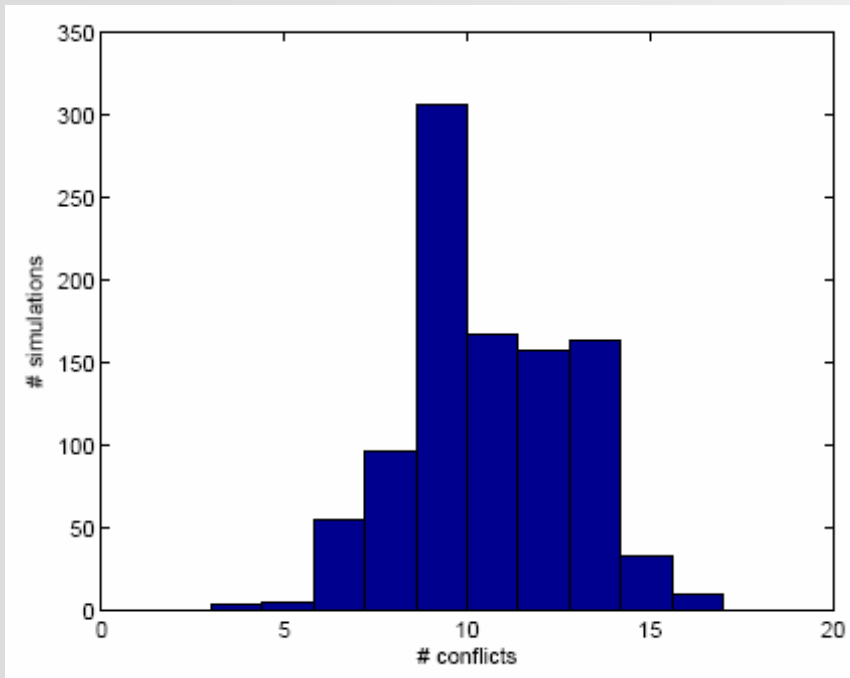
TW's size indicator



Probability of TW hitting

Simulation results

Case 4: Wind + mass + entry point + airspeed uncertainty



← conflicts encountered

- Airspeed uncertainty has a minor impact
 - Conflict and TW hitting probability almost identical with case 3

Simulation results

Summary



Uncertainty	TW hitting probability	Conflict probability	TW size
Wind	Major	Major	↓
Nominal mass	Minor	Minor	↓
Entry point	Major	Major	-
Airspeed	Minor	Minor	-

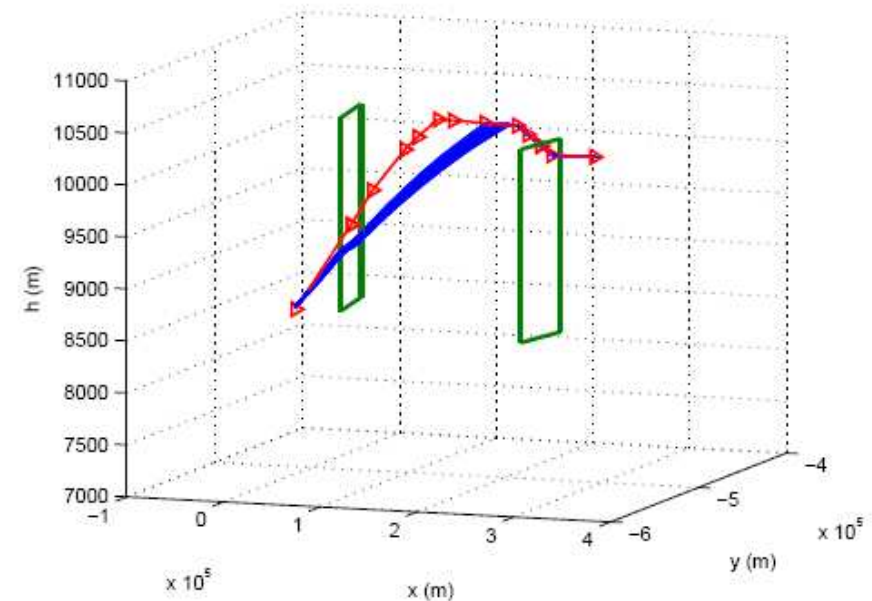
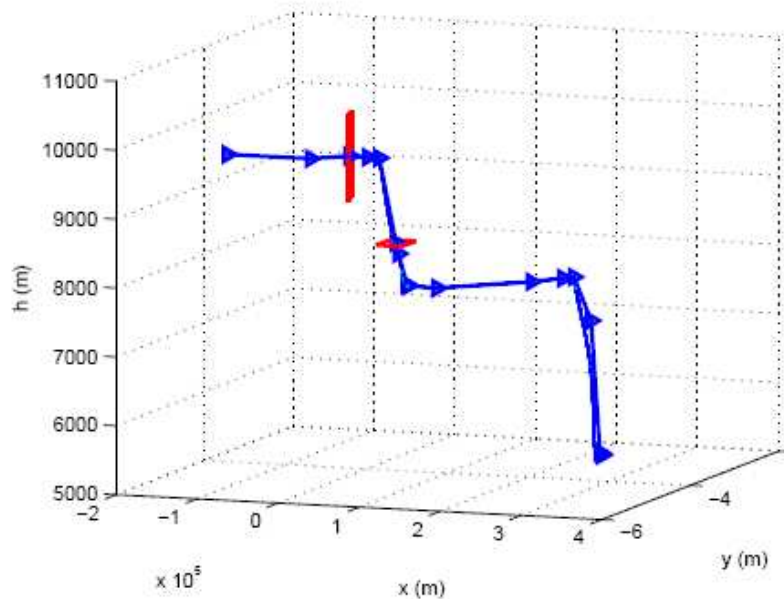
Conflict resolution



- Rank the flights based on their criticality in terms of safety.
- Detect the flights involved in conflict
 - Use the methodology of D2.2.1.1
 - Reachability analysis
 - Game theory
 - Determine the maneuverability freedom of each aircraft involved in the conflict
 - Optimal control approach. Involves solving Hamilton-Jacobi PDE.
- Conflict resolution
 - Place artificial TW in the reachability envelope
 - Evaluate the proposed maneuver via Monte Carlo simulation (1000 simulations)

Conflict resolution

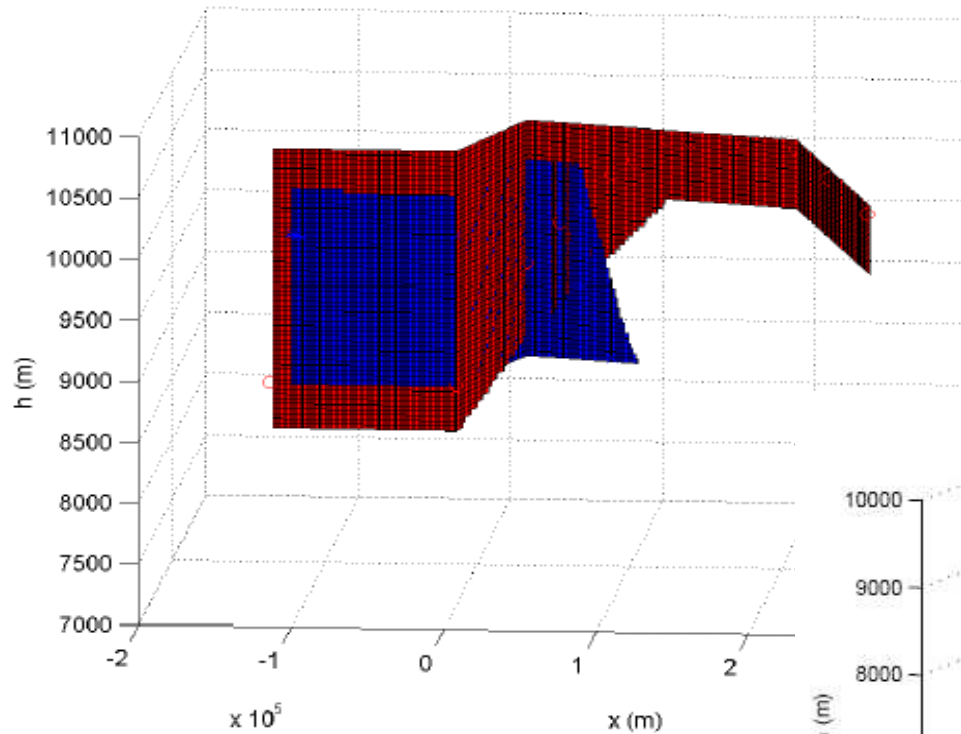
Case study



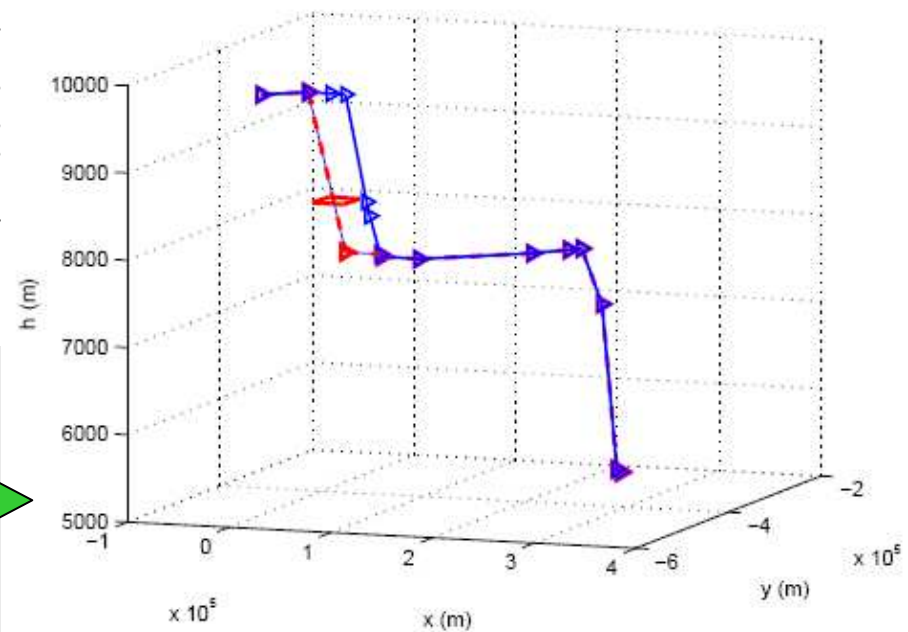
- Flights involved in conflict and their TWs

Conflict resolution

Case study



Backward reachable tubes



Proposed maneuver:
85% reduction in the conflict probability !

Time of Arrival Control

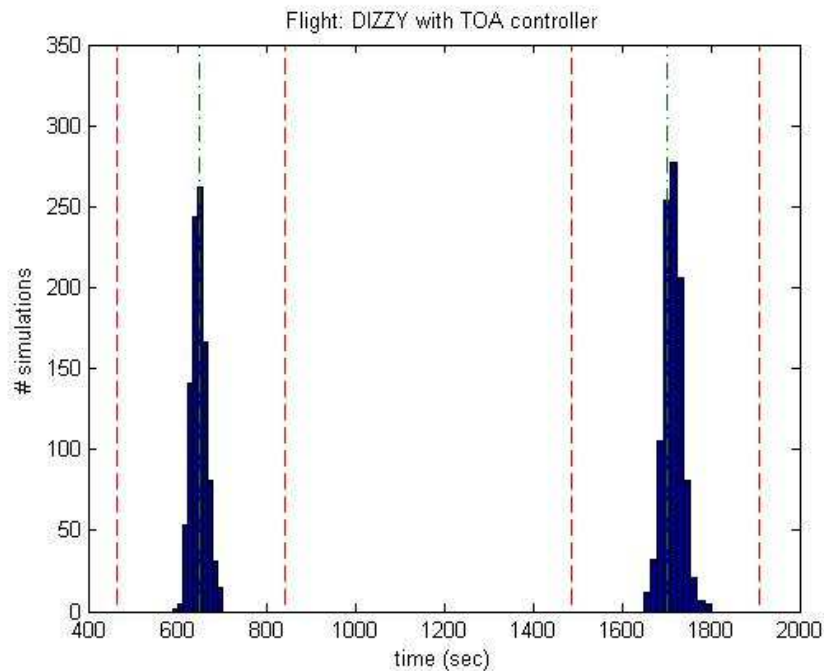


- How to implement it?
 - Continuously add a correction term to the nominal speed
 - Consider only the time window
 - Aim for the center of the time interval

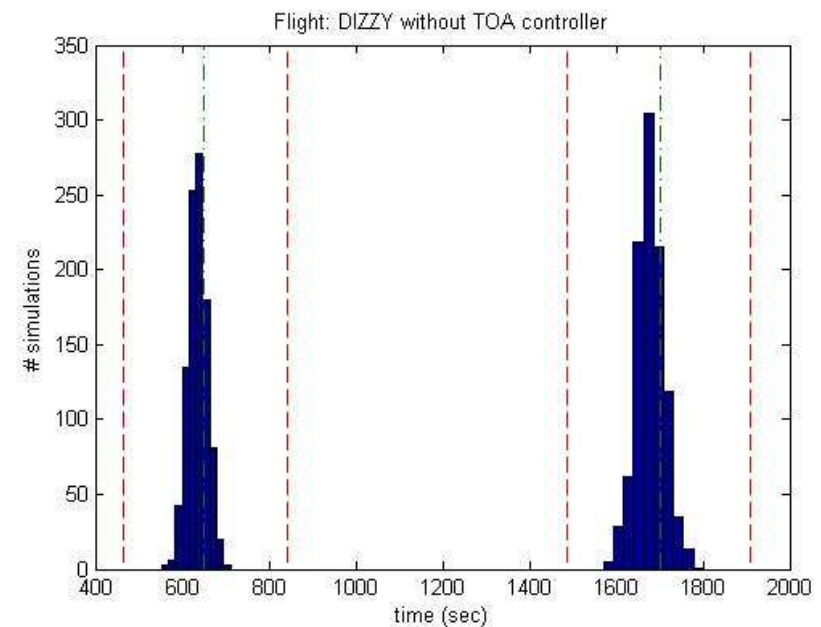
- Initial implementation
 - Monte Carlo simulations to collect statistics
 - Probability of TW hitting
 - Indicates feasible time intervals for the TW
 - Feedback to the TW modeling phase

Time of Arrival Control

Case studies



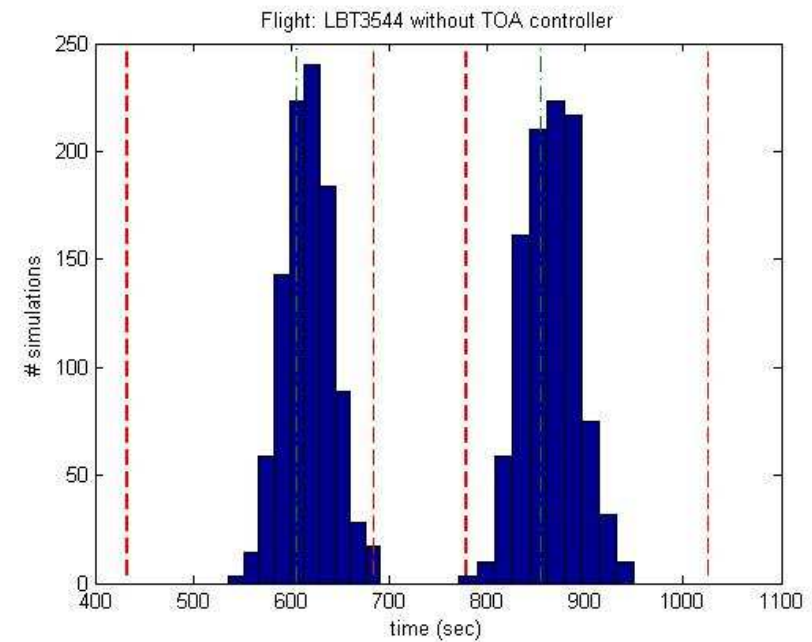
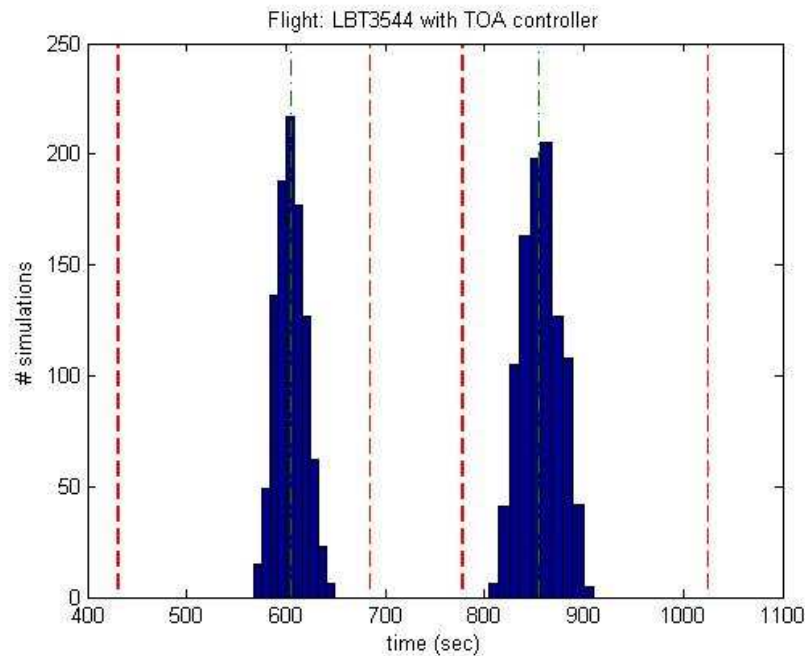
With TOA control:
Narrow distribution
Indication of how narrow TW
can be



- 1000 Monte Carlo simulations with wind, mass and entry point uncertainty
- 31% and 35% reduction in the TW hitting spread

Time of Arrival Control

Case studies



- 48% and 41% reduction in the TW hitting spread

Concluding remarks



■ Safety analysis

- Determined the maneuvering freedom afforded by each TW
- Novel collision avoidance method under TW constraints
 - Theoretical analysis based on reachability and game theory

■ Fast time simulations

- Statistical analysis based on Monte Carlo methods
- Time of Arrival control

■ Future work (motivated by CATS)

- Further research on the reachability-based algorithm
- Formulate an optimization problem to construct conflict free flights

